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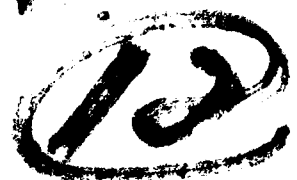
MTR-8224

ANALYSIS OF INTERACTIVE
GRAPHICS DISPLAY EQUIPMENT FOR AN
AUTOMATED PHOTO INTERPRETATION SYSTEM

JUNE 1982

Prepared for

COMMAND AND CONTROL DIVISION
ROME AIR DEVELOPMENT CENTER
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
Hanscom Air Force Base, Massachusetts

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REVIEW AND APPROVAL

This technical report has been reviewed and is approved for publication.

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Off-the-shelf interactive graphics display systems were analyzed relative to the Foreign Technology Division's (FTD's) photo analysis process. "Standalone" and "cluster" display systems were evaluated for their effectiveness in constructing engineering drawings and generating reports. The Evans and Sutherland Multi-Picture System is a representative candidate for FTD use based upon performance and cost considerations.

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Section 1
Introduction

1.1 Summary

As part of MITRE's assessment of FTD's photography analysis process, the application of automation aids to improve photo interpreters' productivity was considered. Specifically, the use of interactive graphics systems was studied for its utility in the preparation of engineering drawings and photo analysis reports.

This document describes commercially available interactive graphics display systems with Computer Aided Design (CAD) software for this application. A set of functional graphics system requirements was developed. Both "standalone" and "cluster" architectures as well as raster and random plot image presentation techniques were examined. We recommend procurement of a photo analysis system using interactive graphics displays as automation tools.

1.2 Conclusions

- Off-the-shelf interactive graphics display system hardware can be used as an automation tool to speed preparation of Photo Analysis Reports and engineering drawings.

- Dynamically refreshed random plot displays are better suited for FTD's photo analysis application than raster scan or storage tube displays.

- Development of application software will be necessary to support the automation of the photo analysis activities.

- The Evans and Sutherland Multi-Picture System is the most suitable interactive graphics system for the PHOTAN application.

Section 2
The Generic Interactive Graphic Display System

Interactive graphics systems offered by different vendors perform comparable functions, irrespective of manufacturer. Common functions include the ability to:

- Input graphics information into the display system and create different graphic presentations by using appropriate computer programs
- Store and retrieve information within a file system integral to the data processing system
- Accept operator commands to the graphics system from a keyboard and other control device
- Provide a hard copy of graphics products.

Although these functions are common to all interactive graphics systems, a range of performance exists among comparable equipment.

Significant differences in the generation of display images exist that can affect both operator and system performance. Three different techniques of display presentation are employed:

- The dynamically refreshed random plot CRT display
- The random plot display with a storage tube CRT
- The raster scan CRT display.

Dynamically refreshed random plot displays employ a stroke generator that creates the image on the CRT using a series of connected vectors. The display image is continually refreshed by an internal control unit. The refresh techniques employed in these systems impact operator performance. A flicker in the display causes eye fatigue for some people and more severe problems for others. Some random plot displays provide for a fixed refresh interval, which is consistent with a flicker-free display, while other displays use variable refresh intervals with the refresh rate dependent upon the display load.

Addressable resolution of up to 4,096 by 4,096 locations can be provided. Resolvable resolution* associated with random plot displays is typically 607,500 locations. A 25-inch rectangular CRT provides a useful display area of 18 by 13.5 inches, and the average spot size is typically 0.020 inches. A large display load can cause flicker with this type of system.

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*Resolvable resolution defines the actual number of points or lines on the CRT screen that can be intensified by the electron beam when creating a display image.

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Random plot color displays are available using beam penetration CRTs. However, this type of display reduces display luminance and flicker-free display load capability as compared to the monochrome CRT displays. The number of colors for the beam penetration approach is limited to four — red, green, yellow, and orange — but many people have trouble distinguishing the red from the orange because these colors are so close in emission characteristics. Thus, only three colors can be guaranteed.

Storage tube random plot displays employ the same type of display generator used in the dynamically refreshed random plot displays previously described. The difference between the two is that once the image is written on the *storage tube* viewing screen, that image is maintained indefinitely without continually refreshing the display image from a dedicated refresh buffer in the random plot displays. Display resolution, both addressable and resolvable, is comparable for both the dynamically refreshed and storage tube devices.

One disadvantage associated with the storage tube is that when updating the display image, the whole image must be erased and followed by a total rewrite of the updated image. The completion of these two operations requires from a few hundred milliseconds to several seconds. The luminance level of a storage tube (typically 2 to 5 foot-lamberts) requires operation in a controlled ambient lighting environment. Color is not available in storage tube random plot displays.

The major impact associated with the relatively long update time of the storage tube is the reduced degree of interactive capability between the operator and the display system. For example, if the operator desires to translate or rotate an object, the entire image must be rewritten. The operator would then observe the new display to determine if the selected view is correct. If not, additional operations must be performed until the desired result is achieved — a slow and cumbersome process.

The light pen is an integral part of most interactive graphics display systems and is used as a pointing and drawing instrument. Storage tube systems will not support the use of a light pen. Because of this and the previously stated considerations, the storage tube display is not recommended for the FTD application and will be excluded from further consideration.

Raster scan displays generate a display image by sequentially intensifying predefined areas of a CRT. Addressable resolution of up to 1,200 by 1,000 points can be provided with this approach. Resolvable resolution is typically 800 TV lines at the CRT center and 600 lines at the CRT edges. Commercially available raster scan displays provide a low-resolution display presentation (typically 525 lines interlaced). While high-resolution displays exist in the commercial market, they are not yet supported by CAD/CAM software. Display luminance and contrast levels are comparable to those obtained with the dynamic refresh random plot display. To familiarize the reader with the characteristics of a raster scan display, the Applicon, Inc., IMAGE System was selected

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as being typical of commercial raster systems. A summary of the characteristics of this system is provided in section 5.

The difference between a display image provided by a random plot display and that provided by a raster scan display is in both the line fitting and detail-rendition ability of each technique. In the random plot display, the image is formed by a series and/or a group of connected vectors or conics. Raster scan displays intensify dots that fall upon a grid of horizontal and vertical lines. Thus, if a 45-degree diagonal is to be drawn, the resultant line structure may appear to have a segmented "stair-step" quality. This approximation to a diagonal may overshoot its intended position and then be followed by an under-shoot (figure 1). The operator's eyes connect the points on the grid, thereby resulting in a "stair-step" line approximation. While draftsmen are often frustrated by this phenomenon due to its apparent lack of precision, they can adjust to it. We have found the adjustment more difficult in those users with the most drafting experience. The error in the raster scan replication can be minimized by corrective circuitry. However, its use is not yet widespread in the industry, especially with interactive graphics raster scan displays. The random plot display is thus better than the raster scan display from the standpoint of graphical image quality.

To develop costs for the proposed display system configuration, representative products were selected that employ random plot and raster scan techniques. The Evans and Sutherland Multi-Picture System, the GRAPHICUS-80, and the ADAGE 4370 Graphics System were selected as representative random plot candidates. The Applicon IMAGE System was selected as the raster scan candidate. Strawman equipment configurations were developed and cost estimates were made for a thirty-two station display configuration using each vendor's equipment. Details are provided in Appendix A.

We believe that the random plot display is a more suitable display technique for this application due to its superior display quality.

The architectures of interactive display systems employ the "standalone" as well as the "cluster" approach. The difference between the two approaches is the amount of processing power provided within the display terminal. In the standalone design, the terminal is capable of performing a large portion of the interactive graphics tasks independent of a host computer. The terminal will require an interface with a host that will provide file storage and the calculations associated with mensuration. In the cluster design, the terminal is provided very little internal processing power and uses an interface display controller that may be shared by a number of terminals. A variation of the cluster design occurs in the so-called "dumb" terminals. In this case, the cluster display controller is replaced by an external host. The terms "intelligent," "smart," and "dumb" are used in the technical literature to describe the relative level of processing power contained within the terminal.

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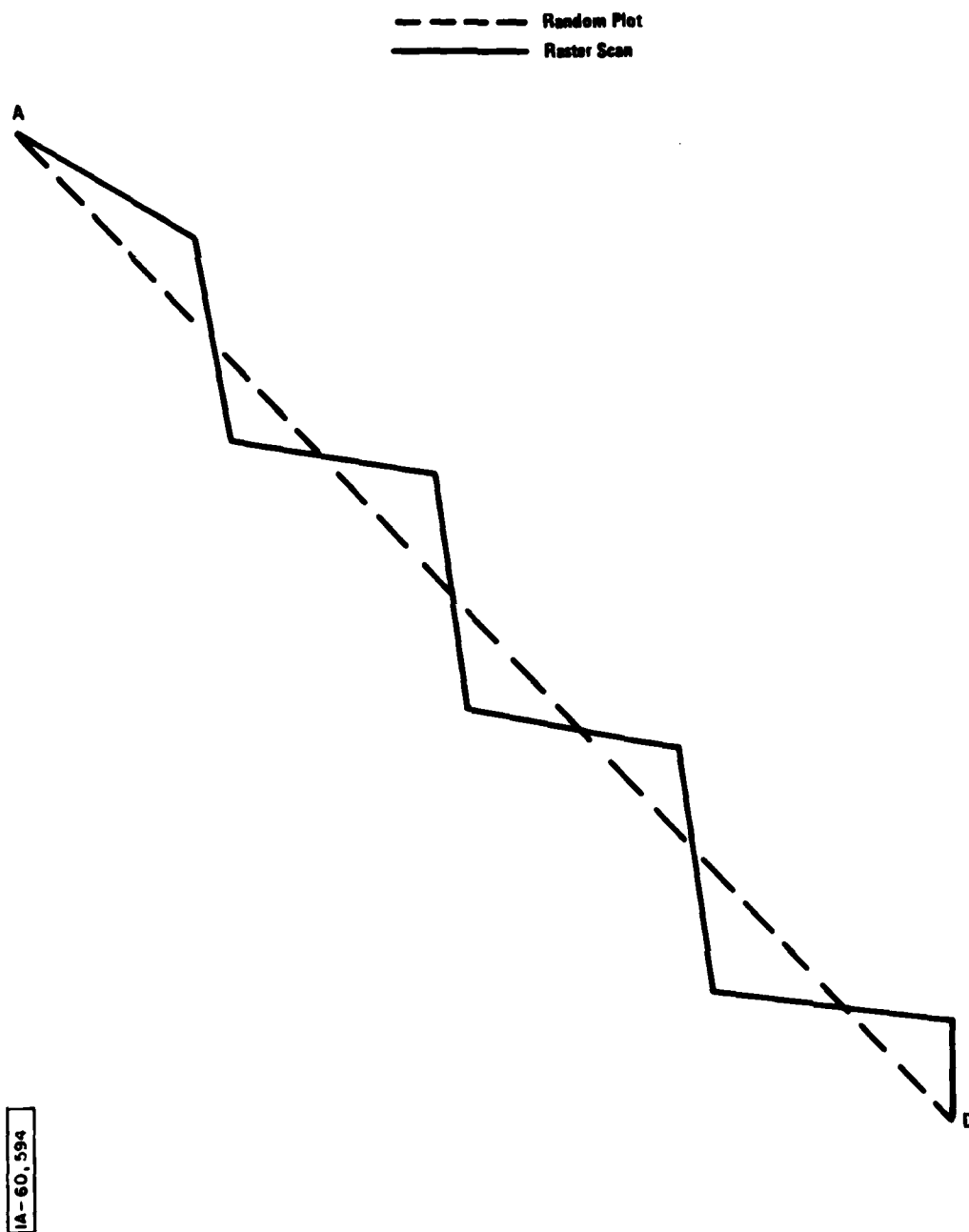
Figure 1. Diagonal Line Approximation of Raster Scan and Random Plot Techniques

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Both the raster scan and dynamically refreshed random plot approaches provide for the display of up to 64 levels of grey. However, if more than 5 levels of grey are used to code display information, the operator's ability to distinguish between them will be exceeded. If discrimination of more than 5 grey levels is required, color should be considered for coding the display information. This will enable the operator to recognize up to ten separate colors (the maximum number of colors that the operators can discriminate reliably). Color can be used to identify the new data added to existing engineering drawings.

Section 3
Representative User
Graphics System Configuration

The following assumptions have been made in developing the equipment configurations and in making cost estimates of equipment from representative vendors:

- The basic configuration of each graphics terminal is assumed to be identical. Equipment not supplied by the vendors as standard display terminal equipment is identified.

- The basic display system configuration is assumed to consist of 32 identical display terminals, each of which contains the following operator interactive devices:

  - Hard Copy Printer
  - Light Pen
  - Track Ball or Joystick
  - A/N Keyboard
  - Function Switches
  - Coordinate Reader Interface
  - Digitizer Tablet

Cost estimates were not made for the following because they are not considered integral parts of the graphics system:

- Host computer and its applications software

- The Display Image Intensification Processor System (DIIPS) — a photo enhancement system

- Coordinate readers

- Spare parts and training aids.

A block diagram of a proposed Photo Interpreter work station graphics terminal is illustrated in figure 2. A certain number of these stations are assumed to be equipped with printer-plotters and coordinate readers. For this analysis, a minimum of eight hard-copy printer-plotters are allocated to a 32-display terminal configuration.

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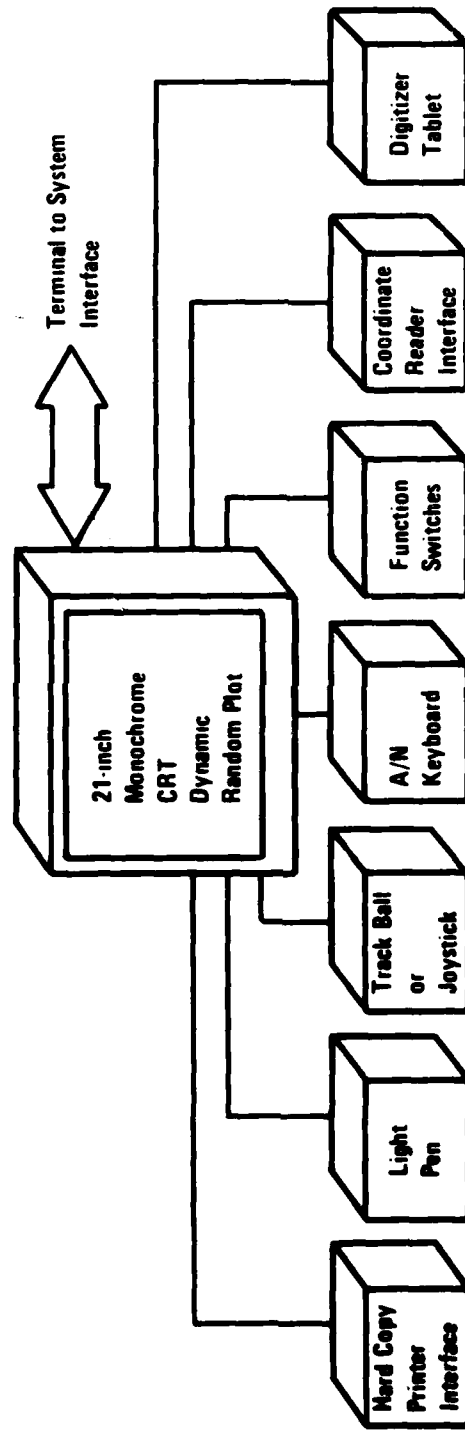
Figure 2. Representative PHOTAN Photo Interpreter Display Work Terminal

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To provide the estimated cost for the candidate display systems, random plot interactive graphics systems offered by three separate vendors were selected. The three vendors are:

- ADAGE, Inc. (System 4370)
- Vector Automation (GRAPHICUS-80 System)
- Evans and Sutherland (Multi-Picture System)

In addition to these random plot systems, a cost estimate was made for a system using raster scan displays for comparative purposes. The raster scan system selected was the Applicon, Inc. IMAGE System.

These four systems were selected as representative of high-performance interactive graphics systems in the commercial marketplace. A product summary and technical description of each system are contained in section 5. Appendix A contains the cost of each system.

Section 4
Technical Description of Representative Systems

This section contains a description of each of the four systems identified in the previous section.

The response times of each system are based on the transfer of a host-resident display list that describes an object consisting of 4,000 vectors (each vector display word consists of 64 bits). This type of object was selected as representative of a complex display image; figure 3 illustrates a 4,000-vector image. The time required for the host/applications software to respond to service requests requiring access to the file management system, to perform perspective to orthographic transformation, rectification, mensuration, and other host-supported functions has not been included in this study. Rather, delays inherent in the operation of the display system from the point of view of the display hardware and its associated imbedded software are identified.

4.1 ADAGE 4370 Graphics Systems

The ADAGE 4370 is an example of a random plot display that employs a version of a cluster graphics system architecture. The host, typically an IBM system, performs the majority of the computing functions of the display system.

The ADAGE 4370 is a high-speed interactive graphics display system designed to interface with an IBM 360/370-compatible I/O channel and observes an IBM 2260 channel protocol. The 4370 employs an Interactive Graphics Programming System (IGPS) developed by Science Applications, Inc. This package resides in an IBM host and provides the software interface with the user's graphics application programs.

IGPS provides automated drafting features, including the capability to:

- Create, modify, restore, save, and erase a graphical image
- Accept characters from each keyboard and allocate these characters to the appropriate image under construction
- Control interrupts and alerts
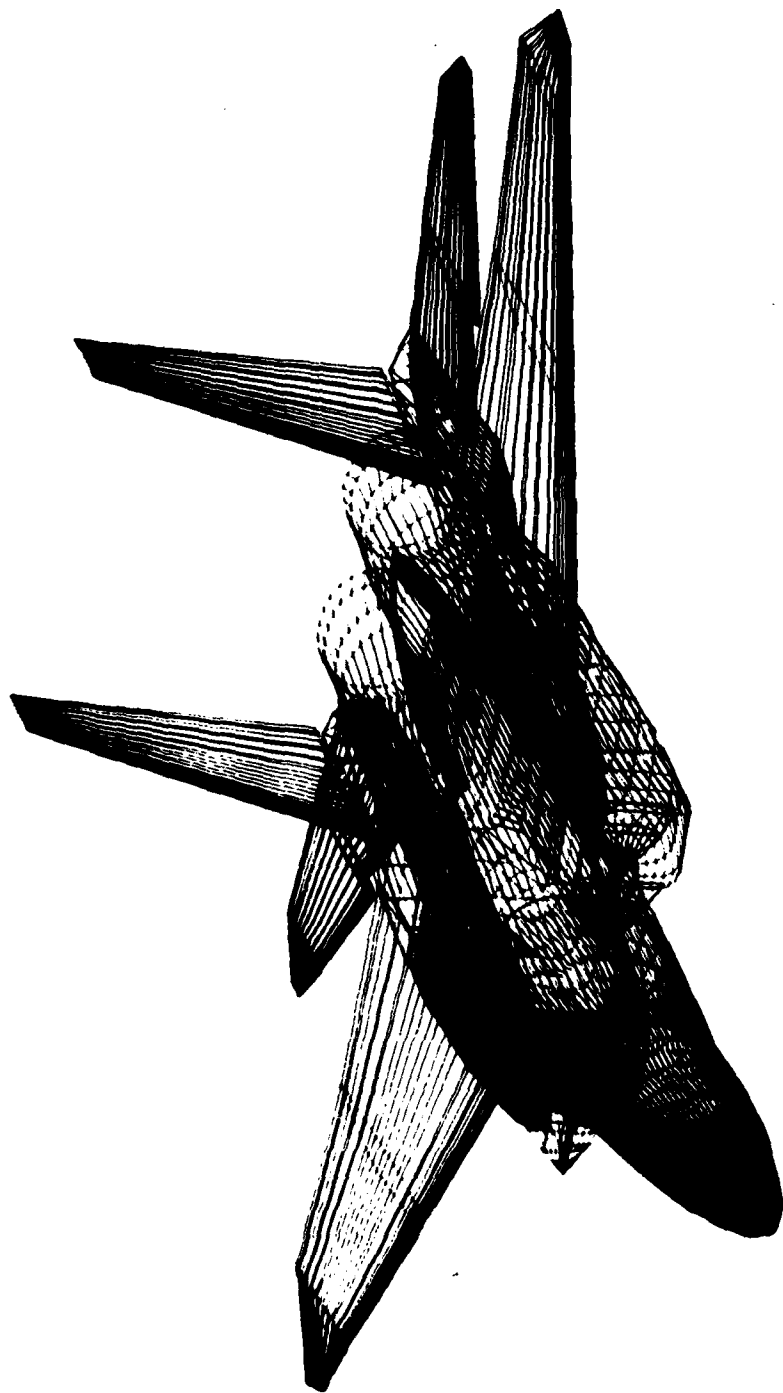- Scale engineering drawings being developed by the operator

Figure 3. Random Plot Display Image Consisting of 4,000 Vectors

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This system can accommodate, concurrently, the full set of 32 terminal users assumed in this study.

The IGPS system is modular in design, and the users may select any or all of the major software functions. The host memory requirement to accommodate this software package is approximately 60K bytes.

ADAGE also offers a software package that provides a capability to generate orthographic and perspective views and provides a plotter interface for the generation of hard-copy engineering drawings. This package is called a Com-puter-Graphics Augmented Design and Manufacturing (CADAM) Applications Software System and resides in the IBM host. This system was developed by Lockheed Aircraft Corporation as an interactive graphics system for computer-aided design and manufacturing. For the FTD application, only the computer-aided design (CAD) portion of CADAM need be considered.* The host memory requirement to accommodate this software package is approximately 200K bytes. This package can provide concurrent service to 32 terminals. We anticipate that both the IGPS and CAD software would be needed to support the FTD application.

The ADAGE 4370 Graphics System is comprised of a channel unit, a control station, and a display station. The ADAGE display is a dynamically refreshed random-plot high-resolution CRT that is driven by a high-speed stroke genera-tor used to draw vectors and characters on the viewing screen. A micropro-grammed graphics processor is used to access the memory of the host computer, to read commands that determine the structure of the image, and to fetch the characters and vectors that determine the content of the display im-age. Figure 4 is a block diagram of the ADAGE 4370 System.

The Channel Unit (CU) is compatible with an IBM 360/370 channel, observ-ing the IBM 2260 channel protocol at rates up to three megabaud (depending on cable length). It also provides error checking and buffering for commands and data to and from the display controller.

The Control Station (CS) contains a display monitor and is identical to the display stations described below, except that the CS contains the display con-troller for a cluster of displays.

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*The remainder of this package (i.e., the manufacturing portion) is not applicable since the manufacturing portion is not relevant.
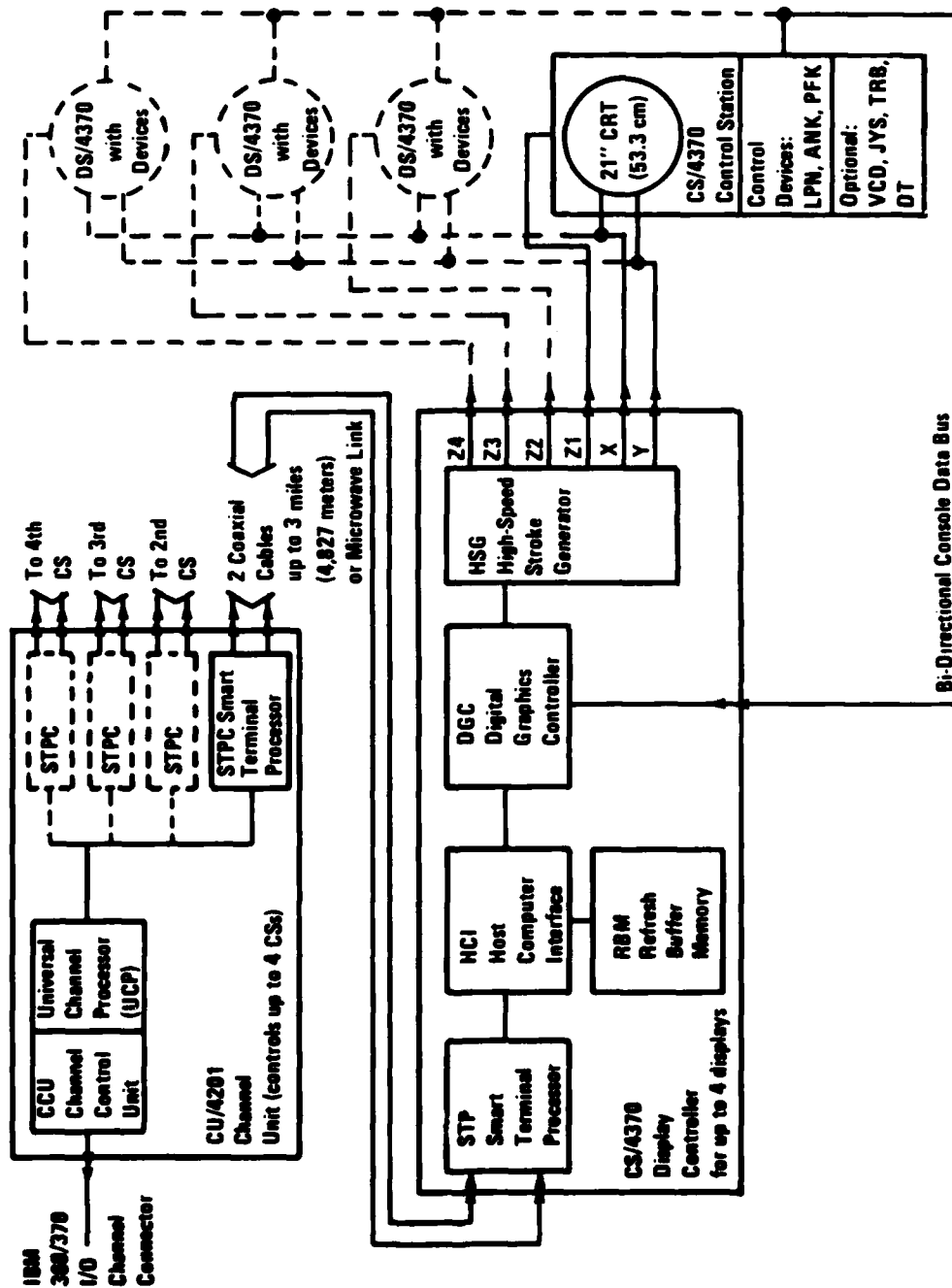
Figure 4. ADAGE 4370 Graphics System

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The display controller (in the CS) receives and transmits data at DMA rates over a pair of coaxial cables in full duplex mode from the CU and provides the necessary error checking of the commands and data. The display controller contains:

- Refresh Buffer Memory (expandable to 128K bytes)

- The Graphics Processor (DGS), which interprets and controls the image commands and data stored in the refresh memory, plus all necessary interrupts

- A stroke generator (HSG), to convert digital to analog values for driving the CRT monitors

One display controller can control four CRT monitors and all interactive devices associated with each.

A display station is comprised of a 21-inch random plot CRT monitor and an alphanumeric keyboard, a light pen, and 32 programmable lighted function keys. An interface at each display station supports control console device options that include variable control dials, joystick, trackball, and digital data tablet in sizes up to 36" x 48". In addition to the CRT display within the station, up to three display stations can be driven by the CS.

The estimated display response time associated with transfer of a host-stored display list consisting of 4,000 vectors depends on the following three factors:

- The number of graphics stations active in the cluster (i.e., the ADAGE display controller will accommodate up to four displays and interactive devices)

- The characteristics of the communications interface

- The processing load of the host processor

If a single display station is interfaced to the display controller and a transfer of a host-stored display list consisting of 4,000 vectors is initiated by the terminal, the action would require a total graphics processing time of 8 milliseconds (an average time of 2.0 microseconds per vector). In the case where the maximum configuration of four display stations are active within the cluster, then the worst-case average time to load the refresh buffer associated with any one of the four displays would be 32 milliseconds, excluding applications software considerations.

With regard to the communications interface, the ADAGE 4370 provides a capability to interface up to 16 display stations to an IBM-compatible channel at a full duplex communications transfer rate of up to 3M bits/second. With the maximum configuration of 16 display stations of a single-channel control unit and each station requesting a separate new display list describing a separate object stored in the host data base (each object description consisting of

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4,000 16-bit words, 1,024,000 bits total), the information could be transferred down the communication link within 1/3 second. In addition to the file transfer, the host is required to support other user functions such as mensuration and file management. For this reason, the actual response time to any display station request will depend on the number of functions supported by the host and the priority assigned to each function.

Summary of the 4370 Display Monitor Features

The ADAGE 4370 high-resolution display monitor (HR15PP) contains a 21-inch rectangular CRT with a viewing area of 18 by 13 inches. The CRT contains a P39 phosphor to preclude flicker at the 30 Hz refresh rate. The typical spot size/line width is 0.015 inches at a maximum display luminance of 50 foot-lamberts. This monitor employs a random stroke image generation technique that creates the display image using a series of chained vectors, arcs, and circles. In constructing display images, the operator is provided a selection of line textures consisting of solid, dash, dot, dot-dash, and end-point lines in 64 programmable and/or manually selectable levels of intensity.

The 4370 display system character generator provides 96 ASCII symbols plus 27 special symbols in program-selectable sizes from .08 to 1.3 inches. The average symbol drawing time is 4.9 microseconds. Customer-required special symbols can be added to the system. However, the symbol generation time will depend on the complexity of the special symbols.

The standard interactive devices provided with the 4370 display include an alphanumeric keyboard, a light pen, and a function keyboard containing 32 lighted programmable function keys. Digitizer tablets and joystick or trackball devices are available as options. ADAGE also offers 2-D and 3-D hardware windowing, circle arc generator, depth cueing, a 128-to-1 zoom capability, and additional 32, 64, or 96K byte refresh buffer expansion as options for the 4370 graphics system.

4.2 Applicon, Inc. IMAGE System

As noted earlier, the Applicon System employs a raster scan display in a cluster system architecture. A number of functions are allocated to a DEC PDP 11/34 minicomputer that operates as display controller for this system.

Applicon's Interactive Multi-Activity Graphics Environment (IMAGE) System provides the hardware and software for a range of graphics processor tasks. The IMAGE System employs the RSX-11M real-time operating system in conjunction with Applicon's Graphics 32 special purpose 32-bit minicomputer. Figure 5 is a block diagram of the IMAGE System.

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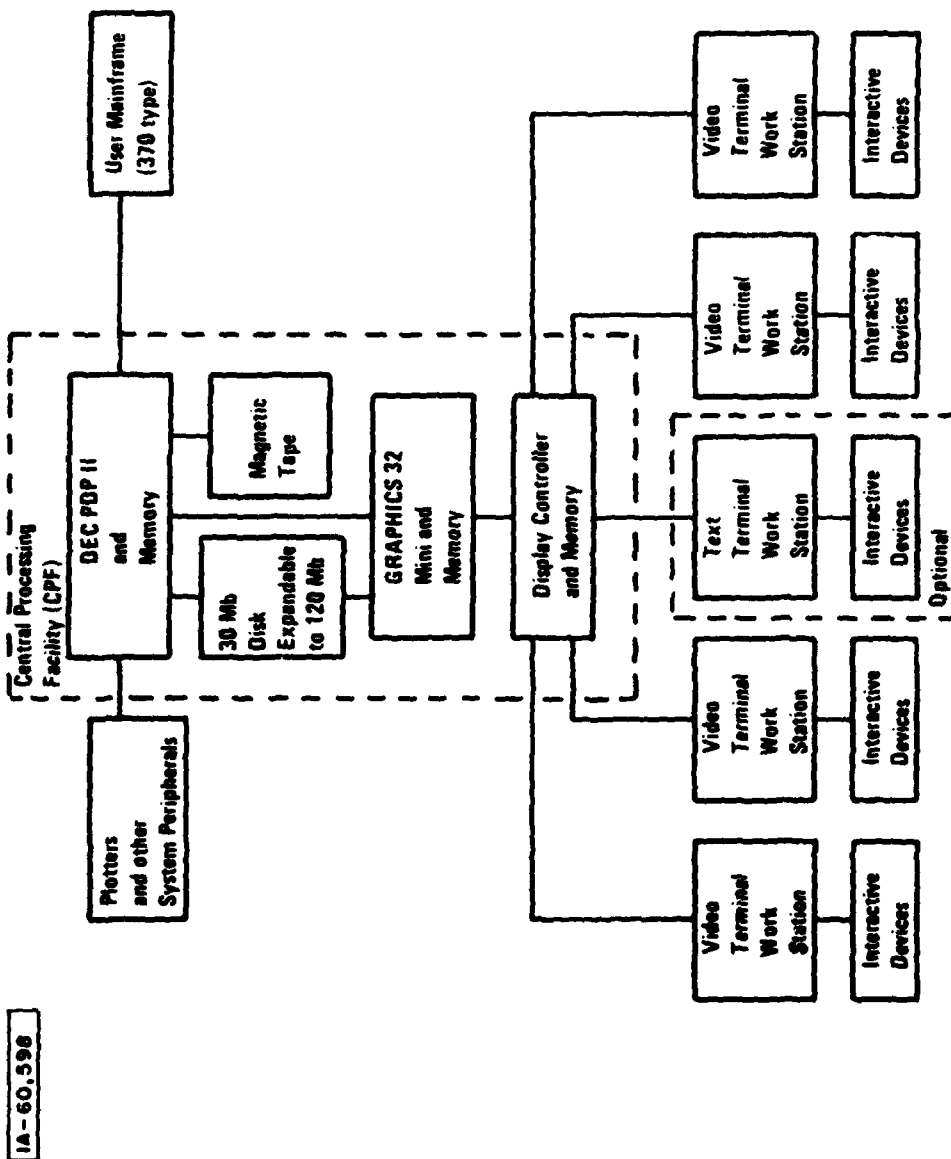
Figure 5. Block Diagram of the Applicon IMAGE System

The following labels appear in the diagram:

- User Mainframe (370 type)
- Central Processing Facility (CPF)
- DEC PDP 11 and Memory
- Magnetic Tape
- 30 Mb Disk Expandable to 120 Mb
- GRAPHICS 32 Mini and Memory
- Display Controller and Memory
- Plotters and other System Peripherals
- Text Terminal Work Station
- Interactive Devices
- Video Terminal Work Station
- Interactive Devices
- Optional

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In the IMAGE System, the primary function of the PDP 11/34 is to control the flow of data between work stations and the central processing facility (CPF). The functions of the PDP 11/34 are as follows:

- Real-time clock

- Read-only memory bootstrap for start-up from disk and magnetic tape

- Single-precision multiply/divide functions

The Applicon Graphics 32 provides the interface between the PDP 11/34 and the work stations. The Graphics 32 performs three functions:

- Data transfer between work stations and memory

- Processing of drawing data for presentation

- Interpretation and processing of operator commands.

The display controller contains a memory to refresh the work station displays. The system can accommodate up to five work stations per central processor, four of which may be used for graphics input and editing, and the fifth, for text input and editing. Each graphics work station consists of a 21-inch raster scan video display, an optional user-defined 64-key function keyboard with visible feedback, an alphanumeric keyboard, and either a 12" x 12" or a 34" x 44" digitizing tablet. A hard copy unit is also available to provide real-time hard copy output of the display. One hard copy unit serves up to four work stations.

The executive program of the IMAGE system is the DEC RSX-11M real-time operating system. In addition, Applicon offers the following three optional operating systems for use with the IMAGE system:

- The AGS/870 2-D Graphics Operating System

- The AGS/880 3-D Graphics Operating System

- The AGS/900 Multi-Tasking Operating System (IMAGE)

The AGS/870 is a package used for processing and storage of engineering drawings and associated data. The AGS/880 supports engineering design and drafting, and the preparation of mechanical, structural, and civil engineering drawings. It also provides perspective representation of solid objects. The AGS/900 supports 2-D and 3-D graphics, program development, and intersystem communications. These packages operate under the control of the DEC RSX-11M real-time multi-tasking operating system.

The Applicon IMAGE System display contains a 21-inch monochrome rectangular CRT with a viewing area of 17" x 14". The display image is created using a 525-line raster generator. The CRT uses a P4 phosphor that provides a 0.025-inch spot size at 50 foot-lamberts full display luminance.

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The standard interactive devices included with each work station consist of an alphanumeric keyboard containing all 96 ASCII characters and a 12" x 12" digitizing tablet. Optional interactive devices include a function keyboard with 64 function buttons and a light pen. Applicon does not yet offer a trackball or joystick.

A color display option is available with a 19-inch color CRT. The brightness level (white) is 30 foot-lamberts and there are seven display colors.

The estimated response time for the system to transfer a 4,000-vector display list from the host computer depends on three factors:

- The number of terminals active in the cluster (the IMAGE System will support up to four terminals per cluster)
- The characteristics of the communications interface
- The processing load of the host processor

If we assume a single terminal is active, 20 milliseconds would be required for the transfer. In the case where four terminals are active in the cluster and each terminal requests the transfer of a 4,000-vector display, the approximate transfer time is 80 milliseconds. This transfer time assumes that the PDP 11/34 is not performing any functions except those required to respond to the terminal(s) requesting this transfer.

4.3 Evans and Sutherland Multi-Picture System

The Evans and Sutherland graphics system employs a random plot cluster display system architecture. Several display processing functions are performed within the DEC minicomputer that acts as display controller.

The Evans and Sutherland Multi-Picture System (MPS) is a graphics display system capable of supporting up to four display terminals per controller. Each MPS can accommodate a wide range of interactive devices, including data tablet, light pen, joystick or trackball, coordinate digitizer, alphanumeric keyboard, function switches, and printer/plotters. The MPS can interface to a host mainframe through the picture-controller interface. Figure 6 is a block diagram of the MPS.

The picture controller is a DEC PDP 11/34. Evans and Sutherland provides up to 256K word memory as part of the Standard Multi-Picture System picture controller. The PDP 11/34 executes programs concurrently under the RSX-11M real-time operating system. Each graphics program consists of a data base describing the objects to be viewed as well as instructions for constructing an object at a display station and interpretation of that station's interactive devices to effect picture modification.
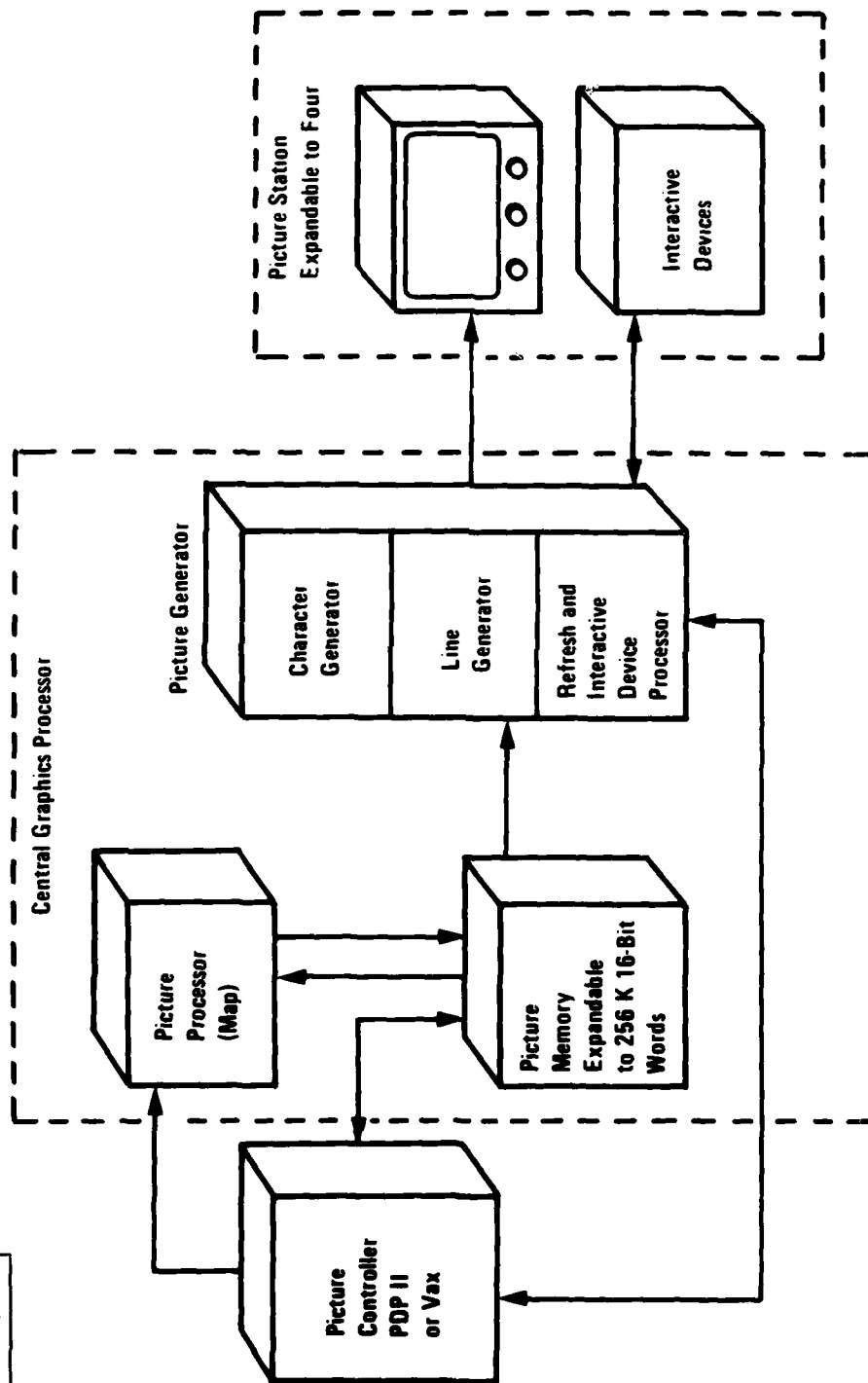
Figure 6. Evans and Sutherland Multi-Picture System

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The Central Graphics Processor (CGP) performs the matrix arithmetic for perspective, 2-D and 3-D image rotation, translation, depth cueing of 2-D and 3-D objects, and provides the ability to zoom and display sections of an object for dynamic graphics interaction. A second segment of the CGP is a picture memory. The picture memory is expandable to 256K 16-bit words allowing the user to store both processed object files and the original data within the terminal controller.

The Picture Generator is the final module in the CGP. Here, processed data is converted to line segments for display, character codes are broken down into basic line segments, and interactive device polling is handled by the Refresh and Device Processor.

The MPS Graphics Software package resides in the central graphics processor and consists of an RSX-11M or VMS operating system and a library of FORTRAN callable subroutines that provide the user with access to the Central Graphics Processor's hardware features. The user interface portion of the MPS is the picture station that consists of a dynamically refreshed random plot CRT display, an operator work table, and an appropriate set of interactive devices selected by the user.

The estimated response time associated with the Evans and Sutherland system to transfer a 4,000-vector display list from the host computer depends on the system configuration. There are two programs and data storage options available with the Evans and Sutherland system. These options are:

- Object data and applications programs stored and controlled by the IBM host

- Object data and applications programs stored and controlled by the DEC PDP-11/34 that is part of the Evans and Sutherland system

The second configuration was used to estimate response times. If we assume the system is configured to accommodate the full 32 display stations, the system response time can be based on that associated with a CGP cluster of four picture stations. In this case, we assume that the four stations simultaneously request four separate display lists from the picture controller file consisting of 4,000 vectors per list. This represents a total of 16,000 32-bit display words (64K 8-bit bytes). Since the DMA channel transfers data at a rate of 500K bytes per second, the time required to transfer these data is quite small, approximately 125 milliseconds. However, it must be noted that this response time is predicated on the PDP 11/34 being dedicated to display update functions; this is not a realistic assumption with regard to the FTD application. The user response times will involve not only the processing load of the PDP 11/34 but also the time required to retrieve data stored on either disk or magnetic tape files. In addition, system response time will be impacted when the operator initiates a service request that involves the host performing rectification, mensuration, orthographic image storage, and other retrieval functions.

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The Evans and Sutherland MPS display contains a 21-inch monochrome rectangular CRT with a viewing area of 16" x 13". The CRT contains a high-efficiency short-decay P4 phosphor as the standard, or a P39 medium-decay phosphor as an option. The typical spot size/line width is 0.020 inches at the maximum display luminance of 50 foot-lamberts. This display employs a random stroke image generation technique that creates the display image using a series of chained vectors, arcs, and circles.

In constructing a display image, the operator has a choice of line textures consisting of solid, dash, dot, dot-dash and end point limits in 64 levels of intensity.

The MPS character generator provides 128 character codes and 256 user-programmable codes in character sizes from .03 to .74 inches. The average symbol drawing time is 5.0 microseconds. The average vector paint time (for a one-inch vector) is 4.4 microseconds. The MPS display refresh rate is program-selectable in three steps of 60, 40, and 30 Hz. The maximum display load at 40 Hz (based on the aforementioned symbol and vector generation time) is an estimated 5,000 ASCII characters, or approximately 6,000 one-inch vectors, or a mix of both.

4.4 GRAPHICUS-80

The GRAPHICUS-80 System produced by Vector Automation is a representative standalone random position graphics display system. The term standalone indicates the capability of the GRAPHICUS-80 system to accommodate the functional requirements for terminal memory management, dynamic viewing operations, and other input/output control that would be assigned to a host computer or graphics processor on a "less intelligent" terminal design.

GRAPHICUS-80 employs a 16-bit microcomputer. Within read only memory (ROM), this terminal stores the operating system as well as the basic instruction set and the arithmetic, utility, and diagnostic functions. The operational software has been developed by Vector Automation.

The GRAPHICUS-80 system can accommodate a wide range of peripheral devices to meet user needs. A light pen, joystick, electronic data tablet and pen, large-sized coordinate digitizer, and printer/plotter can be added. The GRAPHI-CUS-80 can interface to host computers (i.e., IBM 370 type) through an optional 16-bit parallel interface. Figure 7 is a block diagram of GRAPHICUS-80.

The minimum memory size is 32K bytes of refresh random access memory and is expandable to 256K bytes. The graphics operating system (G-CORE) is advertised as complying with the proposed ACM SIGGRAPH "CORE GRAPHICS SYSTEM" standard. G-CORE consists of a firmware package installed in the GRAPHICUS-80 and a small FORTRAN subroutine package for installation in the user's host computer. The host memory requirement to support the subroutine package is approximately 8K bytes.
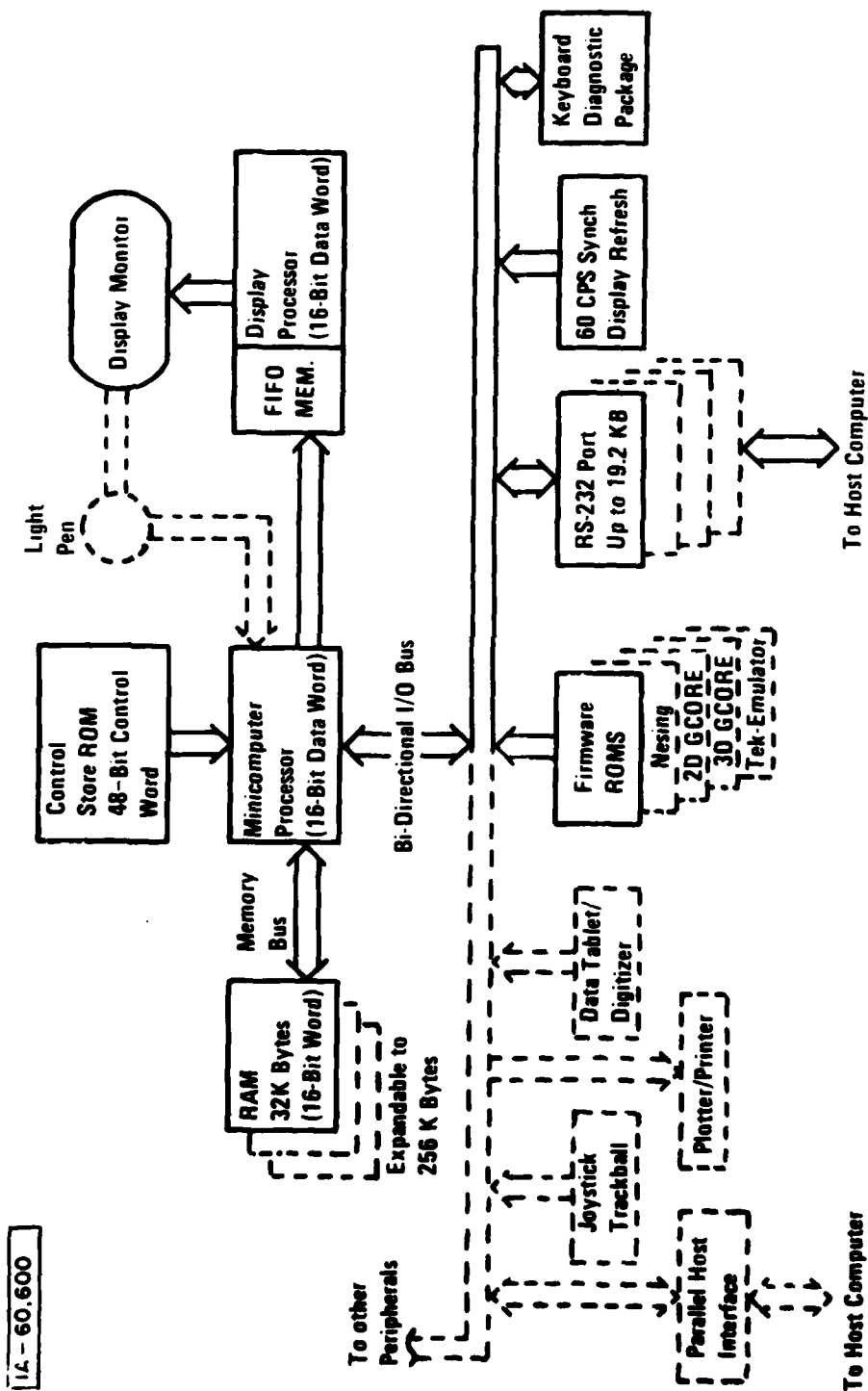
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Figure 7. GRAPHICUS-80 Block Diagram

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The G-CORE firmware package includes:

- Real-time operating system
- Graphical device handlers
- Input/output queue manager
- Dynamic memory allocator
- Display file manager
- Graphics subroutines

The GRAPHICUS-80 display monitor is a dynamically refreshed random plot display. The display provides 1,100 x 800 displayable locations, 16,384 x 16,384 addressable locations, and a variable refresh rate of 60, 40, or 30 frames per second. The display presentation can consist of up to 5,000 standard ASCII characters, flicker-free, at an average screen brightness of 50 foot-lamberts. In addition, the display provides a capability for rotation in fixed increments of 0, 90, 180, and 270 degrees. Blink, scroll, zoom, and windowing are standard features.

The estimated response time to transfer a 4,000-vector display list from a host processor to a GRAPHICUS-80 system depends on three factors:

- Terminal-associated functions
- Characteristics of the communications interface
- The processing load of the host processor

The terminal-associated functions include image modification, translation, scaling, rotation, viewporting, and clipping. These functions are provided by the local terminal hardware and firmware and require no host intervention. The worst-case time to accomplish any one of these functions is less than one refresh time frame at 30 Hz (33.3 milliseconds).

The GRAPHICUS-80 employs an ELA RS-232 interface to the host for each terminal in the system. The maximum transfer rate over this channel is limited to 19,200 bits per second. However, as most hosts do not support data transfers above 9,600 bits per second, the lower rate should be used in calculating transfer times.

As far as the host processor is concerned (IBM 370 or equivalent), the response time to terminal service requests will depend on the number of user system functions that must be accommodated and the priority of functions. In this case, a terminal service request may be held in a queue prior to host reponse.

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Let us assume that the worst-case response time will be imposed by the ELA RS-232 communications interface. If a complete display list describing a display object constructed of 4,000 16-bit words (4,000 vectors) is transferred, 6.6 seconds are required. However, the transfer need only be accomplished once, as the display terminal will store the image in local memory and the operator can now perform some of the interactive graphics functions locally with very little host support.

The 6.6-second response time per display station is based on the Vector Automation system configuration that provides a separate RS232 interface for each display station for communication with the host processor. If the system is configured to time share the RS232 communication interface between the host and the display system, the response time per display station will depend on the number of stations interfaced and the number of service requests. For example, if four display stations are time sharing a common RS232 interface, and each station requests the transfer of a separate display list consisting of 4,000 vectors, then the worst-case response time would be approximately 26.4 seconds for the station initiating the last service request.

The Vector Automation GRAPHICUS-80 display is equipped with a 21-inch diagonal CRT with a viewing area of 17" x 12". The display monitor provides a high-resolution display image based on a spot size/line width of 0.015 inches at 50 foot-lamberts of image intensity. The refresh rate of the GRAPHICUS-80 is program-selectable in three steps — 60, 40, or 30 frames per second. A P39 medium decay phosphor is used to accommodate all three rates, flicker-free. Vector Automation does not provide the special IR-doped phosphor required for light-pen operation.

The GRAPHICUS-80 uses a random plot image generation technique in which the display is created using chained vectors, circles, and arcs. This technique results in a high-resolution, aesthetically pleasing display.

The maximum display load at 30 frames per second refresh can consist of 20,000 one-inch vectors or 5,000 ASCII characters, or a mix of both. The average character write time is 6.6 microseconds, and the average vector paint time (for a one-inch vector) is 1.6 microseconds.

The GRAPHICUS-80 provides scaling, fifteen selectable intensity levels, dash and dot line textures, rotation and axis deflection, blink, scroll, zoom, and windowing.

Section 5
Observations on Commercial Graphics Systems

None of the systems that were considered in this study satisfies all of the user application needs. For example, a means to interface the FTD coordinate readers to the system will have to be developed. Application software for extraction and processing of data contained in hand-held photographs must also be developed.

The interactive random position graphics display systems described in this report exhibit similar characteristics in the areas of resolution, brightness, and contrast. However, when the overall system characteristics are compared, significant differences in operational characteristics become apparent. Table 1 provides a comparison of these characteristics. The Applicon IMAGE System was not considered as a viable candidate for the FTD application because of the unsuitability of the raster scan display technique and the high cost of the system. The following paragraphs contrast pertinent highlights of the three random plot graphics systems examined during this study.

The GRAPHICUS-80 system is new to the market, and only two systems have been delivered to date; only draft system documentation is available. Vector Automation, its developer, is a small company with limited production facilities and a small technical staff. Very little historical data pertaining to the G-80 system is available because of the small number of systems that are operating in the field. As a result, little customer feedback is available. The 2-D and 3-D capability offered by Vector Automation is still in development, and the vendor has made no commitment to a firm delivery date. Because of this product's lack of maturity, we believe that this system should not be considered at this time for the FTD application.

The Adage System 4370 may meet FTD's needs. Some features of this system are not delivered as standard items and must be implemented as options. The design of the 4370 system requires that the operational software (IGPS) reside in the user's IBM mainframe and it requires approximately 60K bytes of core. In addition, functions such as mensuration, system management, and rectification are relegated to the IBM host processor.

Adage now has only seven 4370 systems in the field; consequently, very little operating experience is available. Adage is a moderate-sized company with competent production, engineering, and service organizations. Adage offers a software-development capability to allow tailoring of its systems to accommodate unique customer requirements. However, Adage depends upon Science Applications, Inc. for development and modification of IGPS operational software packages.

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Table 1
Vendor System Characteristics

	Vendor		
	Vector Automation	Adage	Evans and Sutherland
Cost (32 Stations)	$1,125,000	$1,465,600	$1,736,000
Operating System	G-CORE-ACM SIGGRAPHIC	SAM/IGES System	RSX-11M or VMS
Resolution:			
Addressable	16,384 x 16,384	4,096 x 4,096 x 16	4,096 x 4,096 x 64
Displayable	1,100 x 800	1,200 x 960	900 x 650
Refresh Buffer Size	32K bytes Expandable to 256K bytes	32K bytes Expandable to 256K bytes	32K bytes Expandable to 256K bytes
CRT Viewable Area	12 x 17 inches	12 x 18 inches	13 x 18 inches
Interactive Device	Will accommodate full complement	Will accommodate full complement	Will accommodate full complement
Compilers	Not available (in development)	Basic FORTRAN COBOL Assembler Language	Basic FORTRAN COBOL Assembler Language
Estimated Response Time*	6.6 seconds	32.0 milliseconds	66.6 milliseconds

*Estimated response time for each of the systems is based on the transfer of a 4,000-vector display list from the host computer to the system.
See summary of system characteristics in section 5.

Note: Applicon IMAGE system characteristics are not included because a raster scan technique is not recommended for the FTD application.
Applicon system characteristics, however, are provided in the Product Summary and Technical Description, section 5.

Evans and Sutherland is a large, well-established organization that offers extensive software and hardware support to its customers. Evans and Sutherland has approximately 200 systems operating in the field.

Although the per-terminal cost is somewhat higher for the Evans and Sutherland Multi-Picture System, this system provides a cluster architecture which may imply significant off-loading of functional requirements from the central host. The Evans and Sutherland system combination of PDP 11 34 system controller and the Central Graphics Processor (CGP) provides the capability for execution of both graphics and non-graphics programs under a real-time operating system.

Section 6
Conclusions and Recommendations

As a result of this study, we conclude that an off-the-shelf interactive graphics system can be used to improve the productivity in engineering drawing preparation, photo analysis report generation, and system management functions of FTD. To prepare for the acquisition of an automated multi-station photo analysis system, the following recommendations are offered:

- Establish a baseline for the existing system. This effort should:

  - Determine and document the capabilities of the existing systems.
  - Determine and document the means for transitioning present software and hardware to an upgraded system.

- Identify and document the functional requirements associated with the existing system and establish those functional requirements necessary to support new tasks and the anticipated increase in FTD's workload.

- Procure one Evans and Sutherland *Multi-Picture System* to be used as a test bed for developing the procedures for operator aids, and to determine the feasibility of automating mensuration of hand-held photographs.

- Develop a set of detailed technical specifications for an operational interactive graphics system based on identified functional requirements and the results of test bed activities. The purpose of these specifications is to convey the required functional characteristics of a generic user-interactive graphics system to prospective vendors.

Appendix A
Cost Summary

The body of this report described representative graphics systems and the display techniques suitable for the FTD application. In this section, the prices for representative graphics systems using dynamically refreshed random plot displays and a typical raster scan system are listed. Equipment configurations have been selected from ADAGE, Evans and Sutherland, Vector Automation, and Applicon. The costs quoted below include hardware and the standard software included with each system.

A.1 ADAGE, Inc. System 4370

The basic system supporting 32 stations consists of:

- Two CU/4201 Channel Units; each unit supports 16 stations.
  Cost: $36,000 each; total cost $72,000.

- Eight CS/4370 Control Stations; each unit supports four stations.
  Cost: $56,000 each; total cost $448,000.

- Thirty-two DS/4370 Display Stations.
  Cost: $17,500 each; total cost $560,000.

- One Interactive Graphics Programming System (IGPS).
  Cost: $28,000.

- Computer-Aided Design (CAD) package.
  Cost: $200,000.

- Thirty-two Trackballs or Joysticks.
  Cost: $1,300 each; total cost $41,600.

- Thirty-two 36DTs Digitizer Tablets.
  Cost: $7,000 each; total cost $224,000.

- Eight X96KBR. This is an option for expanding the refresh buffer for the eight CS/4370s that will allow each display to present a maximum display load consisting of 6,000 .15-inch vectors.
  Cost: $9,000 each; total cost $72,000.

- Eight Hardcopy Printers.
  Cost: $6,500 each; total cost $52,000.

The total cost for the ADAGE 32 display station system is $1,697,600 or $53,050 per station.

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A.2 Evans and Sutherland Multi-Picture System

The basic system supporting 32 display stations includes the following devices and associated costs:

- Eight Central Graphics Processors (CGP). Purchase of the CGP includes the following components (each processor services up to four terminals):
  - One Picture Station
  - Picture Data Bus
  - Picture Processor
  - Picture Memory with 16K (16-bit) Words
  - Picture Generator with Refresh and Device Processor, Line Generator, and Character Generator
  - Picture Display (21" Rectangular CRT) with 7-foot Interface cable
  - Console Work Station

    Cost: $17,125 each; total cost: $137,000.

- Eight Multiple Picture Station drivers (each driver can service three other displays).

    Cost: $8,000 each; total cost: $64,000.

- Twenty-four Picture Displays.

    Cost: $10,525 each; total cost $252,600.

- Thirty-two Data Tablets.

    Cost: $4,500 each; total cost $144,000.

- Sixteen Light Pens with Data Bus Interface.

    Cost: $4,500 each; total cost $72,000.

- Sixteen Light Pens (without Data Bus Interface).

    Cost: $2,900 each; total cost $46,400.

- Thirty-two Alphanumeric Keyboards.

    Cost: $2,430 each; total cost $77,760.

- Thirty-two Sets of Control Dials.

    Cost: $3,000 each; total cost $96,000.

- Eight Joysticks with Data Bus Analog Interface.

    Cost: $3,460 each; total cost $27,680.

- Twenty-four Add-on Joysticks without Data Bus Analog Interface.

    Cost: $1,970 each; total cost $47,280.

- Sixteen Lighted Function Buttons with Data Bus Interface.

    Cost: $4,450 each; total cost $71,200.

- Sixteen Add-on Lighted Function Buttons without Data Bus Interface.

    Cost: $3,225 each; total cost $51,600.

- Additional Picture Memory 16K (16-bit) Modules that allow each Central Graphics Processor to expand the refresh buffer to a maximum of 256K (16-bit) words.

    Cost: per 16K Module, $3,000; total cost for additional memory $360,000.

- Eight Remote Terminal Interface Connection Devices.

    Cost: $2,455 each; total cost $19,640.

- Two Picture Controllers (PDP 11/34) with 256K memory for each PDP 11/34.

    Cost: $37,000 each; total cost $74,000.

- Eight Printers.

    Cost: $6,500 each; total cost $52,000.

The total cost for one 256K memory Evans and Sutherland 32 Display Station System is $1,539,160 or $49,786 per station.

A.3 Vector Automation GRAPHICUS-80

The basic system supporting 32 display stations includes the following devices and associated costs:

- Thirty-two GRAPHICUS-80 Systems.

    - Thirty-two CRT monitors
    - Thirty-two alphanumeric keyboards with 12 function keys, diagnostic panel and diagnostic software.
    - Thirty-two 32K (8-bit) bytes Refresh Buffer memories

        Cost: $24,500 each; total cost $784,000.

    - Thirty-two light pens

        Cost: $1,200 each; total cost $38,400.

    - Thirty-two Joysticks

        Cost: $1,000 each; total $32,000.

    - Thirty-two Data Tablets

        Cost: $3,500 each; total cost $112,000.

    - Thirty-two 32K (8-bit) byte add-on Refresh Buffer Memory Modules (to support up to 8,000 .5-inch vectors per display)

        Cost: $2,000 each; total cost $64,000.

    - Thirty-two 3-D Translation/Rotation Software Packages

        Cost: $3,000 each; total cost $96,000.

The total cost for the Vector Automation system configuration of 32 display stations is $1,126,400 or $35,200 per station.

A.4 Applicon IMAGE System

The basic system supporting 32 display stations includes the following devices and associated prices:

- Eight AGS/865 Central Processing Facilities. Each unit supports four display stations and each includes the following components:
  - One DEC PDP 11/34 with 128K words of memory
  - Four Digitizer Tablets
  - Four Alphanumeric Keyboards
  - Four Light Pens

    Cost: $123,000 each; total cost $984,000.
- Thirty-two AGS/T16 Terminals

    Cost: $34,000 each; total cost $1,088,000.

To accommodate 32 display stations and to maintain system response time the following components are required:

- Thirty-two 803 refresh memory expansion modules.

    Cost: $5,000 each; total cost $160,000.
- Eight 886 Graphics 32 minicoputers.

    Cost: $15,000 each; total cost $120,000.
- Thirty-two 887 Graphics 32 memory expansion modules.

    Cost: $5,000 each; total cost $160,000.
- Eight Printers.

    Cost: $6,500 each; total cost $52,000.

The total cost for the Applicon IMAGE 32 display station system is $2,564,000 or $80,125 per station.

Appendix B
Reliability Issues

To quantify the reliability parameters associated with a 32-work station interactive graphics system, an availability model was constructed based on the Evans and Sutherland Multi-Picture System architecture. Figure B-1 illustrates a simplified version of this model. Representative Mean Time Between Failure (MTBF) and Mean Time to Repair (MTTR) values from vendor sources were used with this model to develop a value for the system availability parameter. As noted earlier, we have assumed that each station has an identical equipment configuration.

The proposed interactive graphics system will operate in a benign ground environment, representative of a conventional business office. Therefore, the reliability parameter best suited to describe its operation is that of a Steady-State Operational Availability (A_0). A_0 is defined as the probability that the system will be operational at any time t, and is defined:

$$A_0 = \frac{Uptime}{Uptime + Downtime} = \frac{MTBF}{MTBF + MDT}$$

where A_0 includes the time when the system is operating and performing its required function, and when the system is down or cannot satisfactorily perform its required function because of scheduled and unscheduled maintenance and lack of spare parts.

The use of A_0 permits the system designer some freedom to trade off the reliability of the hardware for improved maintenance (i.e., MTBF or MDT), but it behooves the user to first establish a firm maintenance concept that defines the level of repair and the spares that will have to be provided at the operational site or within a reasonable supply distance. For this application, the repair level will be the easily replaceable subassembly or module, but not the entire equipment.

The Availability model developed for this application assumes elements can fail or be down, but that the system can still function satisfactorily if a minimum equipment complement is maintained. It is expected that a call for maintenance will be initiated as soon as a failure is detected. The measured
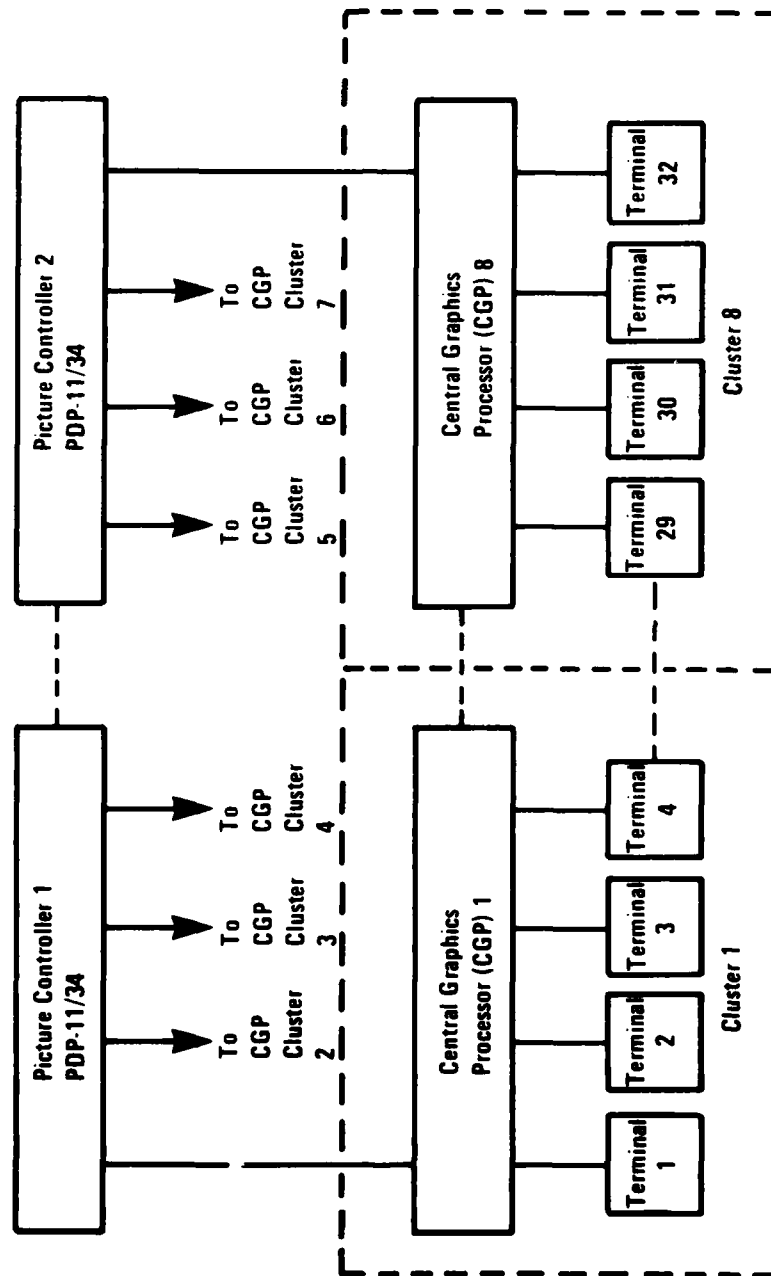
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Figure B-1. Simplified Availability Model

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downtime begins when a call is made and ends when the repair is completed and the system is operational. If the repair is not completed before another element fails and the minimum number of essential equipment is not maintained, the system will then be considered in a failed state even though some degraded operational capability may exist. For purposes of illustration, we have assumed that the minimum number of equipments that must be "up" or "operational" for acceptable system operations are:

- Three out of four terminals per cluster (a cluster consists of 4 work stations)
- Two out of two PDP 11/34s
- Five out of eight clusters

By assuming upper and lower MTBF values that are representative of the configured commercial hardware, upper and lower values for A_o can be established. Within these bounds, the designer has the latitude to trade off equipment MTBF and downtime to optimize this design.

For the configuration under consideration, the following MTBF and MDT bounds have been assumed:

- Mean Downtime for all equipment; Repair at the printed circuit board, module, subassembly level   1 — 2 hours
- Graphics Display Station MTBF   1,000 — 2,000 hours
- PDP 11/34 (Commercial version in an office environment) MTBF   2,000 — 4,000 hours
- Graphic Processor MTBF   3,000 — 5,000 hours

The upper and lower limit of Availability have been derived using the upper and lower limit values of MTTR and MTBF for the representative graphics equipment.

The derived system values are as follows:

A_o (minimum) = 0.99799

A_o (maximum) = 0.99949

To illustrate the meaning of the A_o minimum and A_o maximum, let us consider the operation of the representative system during a twenty-four hour day. With the aforementioned assumptions of minimum acceptable equipment configuration, an A_o minimum of 0.99799 and an A_o maximum of 0.99949 are equivalent to a "system" downtime of approximately 3 minutes and 1 minute respectively.

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